Quantitative Dynamic MR Angiography using ASL based TrueFISP

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Introduction Contrast-enhanced dynamic MR angiography (CE-dMRA) has received considerable attention recently owing to its ability to provide temporal information in addition to the otherwise "static" high-resolution 3-D contrast-enhanced MRA for a variety of clinical indications [1]. While the spatial resolution can reach millimeter and sub-millimeter level, the temporal resolution in CE-dMRA is generally on the order of seconds and the method requires intravenous injection of contrast agent. As a non-contrast alternative, dynamic MRA can be performed with pulsed arterial spin labeling (PASL) in combination with a continuous Look-Locker readout [2]. The appealing feature of spin-labeling based dMRA is the high temporal resolution (on the order of tens of milliseconds), yet the spatial resolution and SNR are not satisfactory due to the low flip angle and/or saturation effects during Look-Locker read-out. TrueFISP [3] is a balanced steady-state free precession (bSSFP) technique that offers high SNR and imaging efficiency. It is ideal for blood vessel imaging due to the intrinsically high T2/T1 ratio of the blood signal. In addition, the T1 recovery of tagged blood is minimally affected by the trueFISP readout, allowing a dynamic temporal window up to 3 blood T1s [4]. Here we show that quantitative dMRA with millimeter spatial resolution and millisecond temporal resolution can be achieved by marrying PASL with a multi-phase inversion-recovery (IR) trueFISP readout.

Methods The dMRA sequence consisted of a multi-phase trueFISP readout preceded alternatively by a slice-selective or non-selective HS inversion pulse. Data were obtained at 60 consecutive TIs (from 125 to 3075ms with a step of 50ms), and there were 20 segmentations. Imaging parameters were: TR=4.98ms, TE=TR/2; FOV=220mm, 5mm slice thickness, matrix=256×256 with 6/8 partial k-space. Each segmented acquisition with 60 phases took 3s with 1s delay time between segmentations. Scan time was 2min 52sec for each slice with a pair of selective and non-selective IR acquisitions. The thickness of the selective inversion pulse was set to 5 / 10 / 15 times the imaging slice thickness to investigate the effect of different arrival time of the tagging bolus. Three flip angles (FA=20 / 40 / 60°) were tested to investigate the potential saturation effects of the trueFISP pulse train. Four female healthy subjects (19-26yr) were scanned on a Siemens Tim Trio 3T MRI scanner, using the product 12 channel head coil. Eight 5mm axial slices with no gap were acquired to cover the Circle of Willis and associated main branches (total scan time 22 Minutes 56ses). Dynamic MRA signals were obtained by complex subtraction of selective and non-selective IR-trueFISP images. Maximum intensity projection (MIP) images were then generated for each phase. Assuming no saturation effects by the trueFISP readout, the dMRA signal (ΔM) can be modeled using the following equations:

$$\Delta M(t) = \begin{cases} 0 & ,0 < t < \Delta t \\ 2M_0 Q(t-\Delta t)e^{-\frac{t}{T_{1a}'}} & ,\Delta t < t < \tau + \Delta t \\ 2M_0 Q\tau e^{-\frac{t}{T_{1a}'}} & ,t > \tau + \Delta t \end{cases}$$

where M_0 is the equilibrium magnetization of blood, T'_{1a} is the apparent longitudinal relaxation time of arterial blood, Q is blood flow (ml/s), Δt is the time for the leading edge of tagged bolus to reach the artery (arrival time); τ is the time for the tagged bolus to fill the artery of interest (infill time). T'_{1a}, Q and τ were fitted using mean dMRA time courses measured from arterial ROIs.

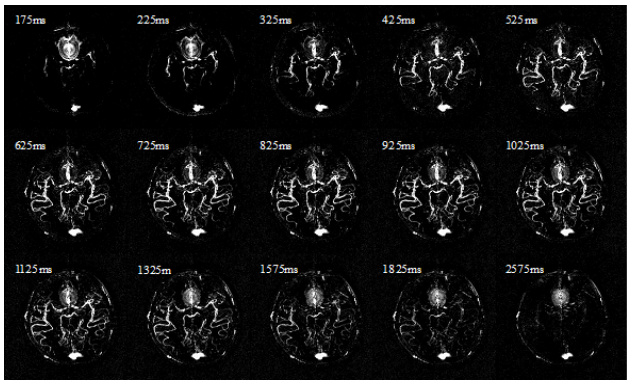

Fig.1 MIP dMRA of a subject with 15 phases from 175ms to 2575ms

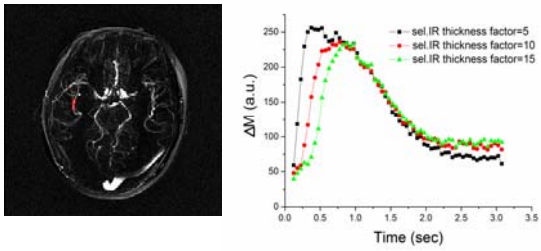

Fig. 2 MIP map across all phases with an arterial ROI shown in red, and ΔM time courses with different inversion bands

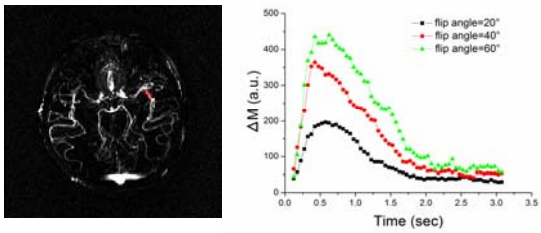

Fig. 3 MIP map across all phases with an arterial ROI shown in red, and ΔM time courses measured with different flip angles

Results Fig.1 shows the MIP images of ΔM at different phases from a representative subject. One can appreciate the anatomical details of the dynamic courses for the blood originated from the internal carotid artery (ICA) and basilar artery (BA) to fill the anterior cerebral artery (ACA), anterior communicating artery, middle cerebral artery (MCA), posterior communicating artery and posterior cerebral artery (PCA) sequentially. Small branches of ACA, MCA and PCA can also be seen in later phases of dMRA. Note the signal in sagittal sinus was due to tagged venous blood superior to imaging slices. Fig. 2 shows the ΔM time course of a MCA ROI acquired with 3 different selective inversion bands. As expected, the bolus arrival was delayed with thicker inversion band (Δt= 0, 73 and 158ms for 25, 50 and 75mm band respectively). After about 40 phases (2s), the ΔM signals returned to baseline. Fig. 3 shows the ΔM time courses of a MCA ROI acquired with different FAs. The ΔM signals are proportional to sin(FA), suggesting little saturation effects on dMRA signals by the trueFISP pulse train. Therefore, it is feasible to employ large FA to improve SNR in our dMRA approach. The ΔM curves can be well fitted using our theoretical model (R^2=0.95). The arterial flow Q, infill time τ and apparent blood T1 (T'_{1a}) were estimated to be 1.34 ml/s, 402 ms and 1128 ms for the MCA ROI.

Discussion and conclusions Non-contrast 4D dynamic MRA with high spatiotemporal resolution is appealing for a number of clinical indications: e.g., arterial-venous malformation, angiomas, aneurysm and tumor vascularization etc. The scan time of the proposed dMRA method can be shortened and image coverage improved using parallel acquisition methods. Arterial and venous phases can be differentiated using spatial saturation pulses. Selective labeling of a single artery is also feasible. Dynamic MRA using ASL based trueFISP may complement CE-dMRA and digital subtraction angiography (DSA) in dynamic evaluation of vasculature.

References [1] Reinacher PC, Neuroradiology 2007; 49 S1: S3-13. [2] Gunther M., et al. Magn Reson Med 2001; 46:974-984. [3] Oppelt A, et al. Electromedial 1986; 54: 15-18. [4]. Wu W-C and Wang J. ISMRM 2008, #3080